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Mr J. F. Campbell
with the respects of J. D. Dana

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NOTES ON SOME OF THE PHENOMENA OF THE GLACIAL ERA AND THEIR ORIGIN; IN BOOK NOTICES

BY JAMES D. DANA.

Geological Survey of Canada, ALFRED R. C. SELWYN, Director. *Report of Progress for the year* 1873–4. 268 pp. 8vo. Montreal, 1874. (Dawson Brothers.)—No annual Geological Reports on this side of the Atlantic exceed in value those of the Canada Geological Survey. * * * *

Mr. Selwyn states, in his Introduction, that the facts gathered tend to prove that *lithology* among crystalline rocks is not a safe test of geological age, observing that this conclusion is favored by the recent researches of Mr. Richardson in British Columbia, which show that "epidotic, chloritic and serpentinous rocks, with crystalline limestones and magnetites, are as characteristic of Upper Paleozoic, and perhaps also of even later formations, where they have been subjected to an equal amount of plication and folding, as they are of the oldest Paleozoic and protozoic strata, such as those of Eastern Canada and the New England States." He observes that Sir William Logan has been carrying forward extended and thorough investigations in Canada on this point, connected with a study of the true stratigraphical relations of the rocks, and that he will give a full report as soon as "the necessary examinations have been completed." * * * *

In his Report on the Northwest Territory, Mr. Selwyn states that, going westward from Fort Garry (or Winnipeg), the capital of Manitoba, lat. 49° 52′ N., long. 96° 50′ W., *only drift*—sand, clay and gravel—was seen along their course for a distance of 885½ miles. The first terrace plain in that direction has an average breadth of 120 miles, is 75 to 100 feet above Lake Winnipeg, and but 700 or 800 feet above the sea level. The drift of its surface is apparently underlaid at no great depth by Silurian and Devonian strata. Its western limit is marked by a range of low hills extending from Pembina Mountains by the Riding, Duck and Porcupine Mountains, to the Basquia Hills. Here there is a rise to a *second* prairie level, which is undulating or hilly and "attains an average elevation of 1600 feet." A *third* prairie level commences at the Thickwood Hills, 20 miles west of Carleton; it is 1900 to 2000 feet above the sea; the limestone boulders on it do not reach farther west than the longitude of Fort Pitt. Sand is the material of the deposits, and it is mostly unstratified, becoming imperfectly stratified and calcareous to the westward. At Fort Ellice, the valley of the Assiniboine (as stated by Dr. Hector) is 240 feet deep: the upper 100 feet consist of this drift deposit, and the rest of Cretaceous beds. * * * *

With regard to the *Drift*, Mr. Bell states that *the direction of the striæ* to the north and northwest of Lake Superior is in general *southwestward*, and that the same course prevails as far east as the Ottawa River; and "there is little doubt that the same course prevails for some distance to the north and west of Lake Winnipeg; for the plains west of the lake and of West River are covered with the debris of rocks derived from the east of the lake."

These observations on the scratches northeast of Lake Huron confirm the statements of others, and sustain the conclusion of the writer therefrom*—that the greater height of the ice-surface in Canada was over the watershed between the St. Lawrence and Hudson Bay. The facts from the vicinity of Lake Winnipeg show further that a line of *greatest height* was continued from this region northward or northwestward. It does not follow that the height along this line to the northward was as great as over the watershed; but only that the greatest height for those latitudes was there, or that it was great enough to determine a southwestward movement in the ice. The greatest height would have been where there was the greatest amount of precipitation, supposing the melting the same; and this, as the writer observes in the same article,† would have been toward the southern and coastward limit of the glacier. Over the interior of the continent, both the small amount of precipitation and the high degree of heat in summer would have put the southern limit of the ice north of the limits of the United States. The summer isotherm of 72° F., which passes over southern Ohio—the south limit there of the drift,—extends in the interior, about the meridians 98° to 105°, northward to latitude 47°; and over this area and also its extension far north and likewise far west to a line passing by Sierra Nevada and the Dalles in Oregon, the amount of annual precipitation, according to Schott's Rain Chart, is *sixteen inches and less.* * * *

An Essay concerning important Physical Features exhibited in the Valley of the Minnesota River and upon their signification; by G. K. WARREN, Major of Engineers and Bvt. Maj. General, U. S. A. 22 pp., 8vo., with several maps. Engineer Dept., U. S. Army. —Major Warren draws attention, in this Report, to the width and extent of the valley of Minnesota River (one of the head tributaries of the Mississippi) a feature continued even to its source in Lake Traverse, and to the great disproportion between its size and that of the stream now occupying it. He next states facts, derived from Prof. H. Y. Hind and other observers, respecting the great extent of the level region and stratified drift deposits about Lake Winnipeg, and the uninterrupted continuation of the deposits to Lake Traverse. The conclusion deduced is that in the Glacial era the land to the north about Lake Winnipeg was more elevated than now, so that the drainage from that lake was to the south, instead of, as now, through Nelson's River, to Hudson Bay; and that Lake Traverse was really the south end of Lake Winnipeg, and Minnesota River the outlet by which the great flood of waters passed south to the Mississippi. The Mississippi River would then have had its head waters in the streams that enter Lake Winnipeg from the west and north.

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* This Journal, III, ii, 324; v, 204.

† Ibid, v, 206, 208.

The highest part of the region about Lake Traverse is 995 feet above the sea, while that of Lake Winnipeg is about 630; so that a rise of but 365 feet to the north would produce the change of course. He observes that the height of the lake terrace above the ancient bed west of Pembina, as given by Mr. Owen, is 210 feet; that the lake bed there is about 50 feet above Red River, and this river at this point is about 100 feet above Lake Winnipeg; and hence he adds, "this lake terrace is 360 feet above the level of Lake Winnipeg—a height sufficient, as I have shown already, to extend the present Lake Winnipeg to Lake Traverse." Professor Hind, as quoted, says that "the Pembina Mountain [but 210 feet high] is *par excellence* the ancient beach in the valley of Lake Winnipeg. Dr. Owen thus describes it as it presents itself a few miles south of the 49th parallel."

When the southward slope of the surface came to its end through a northern subsidence, Nelson's River became the outlet —a narrow gorge abounding in water-falls. J. D. D.

4. *An examination of the Theories that have been proposed to account for the Climate of the Glacial Period;* by THOMAS BELT, F.G.S. (Quart. J. Sci., Oct., 1874.)—After a discussion of the merits of various theories for accounting for the cold climate of the Glacial period, Mr. Belt argues strongly for the old theory of a change in the obliquity of the ecliptic. He admits that the decision of astronomers is against it, but he holds that "until astronomers have reconsidered this question with the light of our present knowledge of the figure of the earth, geologists should not be prevented from speculating on the probability of great changes in the obliquity of the ecliptic having caused former great variations of temperature." Mr. Belt also touches on the lowering of the sea-level by the accumulation of ice over the land, and says that, on the supposition that the ice was equal in the two hemispheres at the same time (the view he sustains), the lowering of the sea-level "could not have been less than 2000 feet, and may have been much more."

Since any lowering of the water line of the ocean by the abstraction of water to make the Glacial ice would have been alike on all the coasts of the world, Mr. Belt's estimate of the amount in the Glacial period is open every where to demonstration. On the Atlantic border of North America, such a change—which is equivalent to a rise of the land of 2000 feet—would have led to an immense amount of valley-excavation along the many rivers; and such valleys, so recently made, should still intersect the alluvial, Tertiary, and Cretaceous deposits of the very wide coast region of the continent, or be but partially obliterated. Instead of this, this coast region is remarkably flat and even and is intersected only by narrow river channels. There is nothing comparable in any part to the fiords of Glacial latitudes; and, more than this, there is little evidence of recent excavation very much below the present sea-level. The same fact is true of other continents.

A source of cold not considered by Mr. Belt is suggested in the writer's Geology (new edition), viz: that there was *an elevation of Arctic lands sufficient to exclude the Gulf Stream from the Arctic regions.* If these tropical waters—which now distribute over the northern latitudes, according to Mr. Croll, 154,959,300,000,000,000,000 foot-pounds of energy in the form of heat per day—were thus prevented from making their circuit over the polar regions north of the continents, the flow northward by Iceland would be stopped, and, owing to the northeastward trend of the American coast from Florida to the southeastern cape of Newfoundland, the Gulf stream would be mostly confined to a circuit within the tropical and warm-temperate zones.

This cause, in addition to the direct cold-producing effect of an increased amount of Arctic land, would thus have been sufficient to produce all the lowering of temperature needed for a Glacial period. And it would have made an epoch of cold in any period of the globe. Moreover, the deep submergence of Behring's Strait (now but 180 feet in depth), and of the region around, by letting in the Pacific tropical current, would at any time, as in the Miocene period, have made a warm Arctic. This explanation of the warm Arctic climate in the Miocene, which is presented in the Geology,* was suggested to the writer, as there stated, by Professor F. H. Bradley; and the other respecting Glacial climate may be considered a corollary from it.

Professor A. E. Verrill has recently called the attention of the writer to another effect from this confining of the Gulf Stream to the Atlantic: that the heat which is now carried to the north would then be kept mainly within the warm temperate and tropical latitudes of the ocean, and that, consequently, the other requisite of a Glacial era, *very abundant precipitation, would have existed concurrently with that of unusual cold over the land*—conditions, as Professor Verrill states, that would make a storm region of tremendous effects over the ice within 300 or 400 miles of the warm sea limit. All the conditions demanded are therefore met by this theory.

The high-latitude changes of level here appealed to may have produced effects at intervals through all geological time, though of feeble intensity in the Paleozoic. Agassiz, in 1840, in his *Études sur les Glaciers*,—a work that made an epoch in geology by its demonstrations of the glacier origin of the Drift,—suggested also that the principal epochs of life-extermination in geology were epochs of cold—" que les plus grands froids ont terminé chaque epoque géologique,"—cold being a cause of extermination; and there is reason to believe that he was right as to some at least of the epochs. The writer recognizes two such in his Geology, one at the close of the Carboniferous, and another at the close of the Cretaceous (the latter in the 1st edition of the work); and he alludes to the subject here in order to give the credit of first bringing forward the principle to Agassiz. "The indications of floating ice which Ramsay has found in the British Lower Permian may be a mark of the slow approach of such an era of cold"* at the close of Paleozoic time; and the Triassic rocks of eastern North America seem to bear, in their large rounded stones and the nature of the beds, evidence that the excessive precipitation and also the cold of such an epoch had then not yet passed.† J. D. D.

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* Manual of Geology, 2d edit., p. 541.

5. *On the Submergence during the Glacial period.*—Professor Croll, in the Geological Magazine for July and August, 1874, presents the following as the cause of the apparent subsidence, or rise in the water level, which took place before the disappearance of the ice of the Glacial period; or, as he has it, the submergence during the Glacial period, he holding that the whole period was a period of lower level of the land than now. He proceeds on the supposition, before argued for by him, that the cold of the Glacial period was due to the eccentricity of the earth's orbit, and that it affected the northern and southern hemispheres alternately.

The removal of two miles of ice from the Antarctic Continent would displace the center of gravity 190 feet, and the formation of a mass of ice of one-half this thickness in the Arctic regions would carry the center of gravity 95 feet farther in the same direction. Further, the area of the Antarctic ice-cap being $\frac{1}{23\cdot46}$ of that of the ocean, therefore, allowing 0·92 for the density of ice, the melting of 25½ feet of ice from the cap would raise the general level of the ocean one foot; and a mile of ice, 200 feet. The other mile of ice melted is balanced by the abstraction of water to add a mile of ice to the Arctic. These numbers added, says Mr. Croll, give 485 feet for the amount of submergence that would be thus occasioned at the North Pole, and 434 feet for that in the latitude of Edinburgh; or if the ice had twice the supposed thickness, the amount of submergence would have been twice this amount.

The facts from Eastern North America do not appear to favor Mr. Croll's conclusion. The amount of subsidence indicated by raised shell-beds on the St. Lawrence at Montreal, near latitude 45°, was about 500 feet; on the coast of Maine, near latitude 44°, only 200 feet, when it ought by the theory to have been but a few feet less than at Montreal; and along the southern shore of New England, near latitude 41°, only 50 to 100 feet, the larger of which numbers is much less than a fourth of what the theory requires. It seems hence to follow that the curve of submergence did not correspond with the curve which would have been produced in the ocean's surface by a change of the center of gravity.

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* Manual of Geology, 2d edit., p. 431.

† The agency of ice in the deposition of the Trias of Eastern North America has been suggested by T. A. Conrad, and also by H. Wurtz, and by both in 1869.

The Coral Island subsidence over the Pacific, which affected a very large portion of the tropical part of that ocean, must have been in progress through the Glacial period, and the amount of it was certainly several thousand feet. Here was a great change of level *in the tropics*, which no change in the earth's center of gravity could have produced. It was in a sense local, the continental lands adjoining not sinking with the ocean's bottom, nor all parts of the ocean alike. It is evidence that the cause of the great change of water level during the Quaternary age, as well as in earlier time, resides in the crust itself. The facts from the shell beds of the St. Lawrence and the coasts of New England appear to be equally evidence of a *bona fide* subsidence, which no cause affecting the ocean as a whole will account for. J. D. D.

6. *Recent Changes of Level on the Coast of Maine, with reference to their origin and relation to other similar changes;* by N. S. Shaler. (20 pp., 4to, 1874, from the Mem. Bost. Soc. Nat. Hist., ii, 322.)—The evidence of the changes of level here discussed was gathered from the Quaternary deposits of Maine and of the coast south. Professor Shaler concludes that the evidence sustains the view that there was a subsidence or "depression" of the land increasing in amount, though somewhat irregularly, to the northward, after "the first division of the Glacial period;" and that subsequently there was "a return of the ice in the shape of a set of local glaciers which covered the shore at Mt. Desert, and along most of the territory at least as far as New Brunswick, and persisting until the final re-elevation of the land to near its present level."

The cause of the depression is discussed in the closing pages. He remarks that the only hypothesis as yet advanced to account for it is one proposed by Adhémar; overlooking the fact that the writer, first in 1856,* offered another, referring the great Quaternary movements of the crust,—the *upward* for the Glacial period, the *downward* for the Champlain or Fluvial period, and then a succeeding *upward* rise—like the other great movements, to the lateral pressure in the earth's crust due to contraction from cooling.

Adhémar's hypothesis, as explained by Mr. Shaler, supposes a displacement of the center of gravity in consequence of the unequal accumulation of ice at the poles, much like that recently proposed by Mr. Croll. Professor Shaler rejects this explanation, chiefly because the Glacial phenomena of the two hemispheres have not yet been proved to be alternate, and because the amount of depression does not increase with regularity over the whole northern hemisphere; and then presents his own hypothesis, which attributes the depression to *the weight of the ice-mass over the land.* After speaking of the continents as having their positions determined by "constant tensions" (meaning, perhaps, to include *lateral pressure*, which far exceeds tensions in importance) and the weight of the mass, he says, "it seems evident enough that we may more reasonably look to the weight of the ice accumulated on the continents during the Glacial period for the depression of the land-areas it occupied, than to any other cause."

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* Amer. Jour. Sci., II, xxii, 346. The same conclusion is involved in his earlier paper in 1846, 1847.

This theory assumes that a cap of ice "a mile or more thick," equivalent, as the author states, to half this thickness in "ordinary rock," depressed the earth's crust 500 feet and upward over the area from the St. Lawrence and great lakes to the Arctic, notwithstanding that the arched crust had a thickness of probably 100 miles. There is no doubt that such a weight—equal to a cap of rock, say one hundredth as thick as the earth's crust—would tend to cause a depression, for this tendency exists even under any small weight. But, considering the form and nature of the crust, and the lateral or tangential pressure existing throughout it, shown by Mallet to be enormous, it seems to be far from probable that mere weight can account for so great a movement. Lateral pressure has been the chief agent in oscillations of level and mountain-making over the earth; since Archæan time, making (1) the Green Mountains, (2) ridges in Nova Scotia and New Brunswick, and (3) the Alleghanies, on the *eastern* border of the North American Continent, at long intervals; and *subsequently*, after other long intervals, raising (1) the lofty Wahsatch Mountains and Sierra Nevada, (2) ranges of Cretaceous mountains, and (3) Tertiary ridges, on the western side of the Continent; besides (4) elevating, during the Cenozoic, the great Rocky Mountain mass 8,000 to 10,000 feet, —an effect that no weighting was employed to produce. And even in the Quaternary, though perhaps the work was begun before, there was the great subsidence over the tropical Pacific—the coral island subsidence (and another similar, probably over the tropical Atlantic), which the weighting of the islands by coral growths was certainly inadequate to produce, and which is naturally another consequence of the uneasiness of the crust owing to lateral pressure.

Here are vast results — elevations and subsidences — accomplished by lateral pressure. Now, that elevation of the land over the higher latitudes which brought on the Glacial era, is a natural result of the same agency, and a natural, and almost a necessary, counterpart of the coral island subsidence, which must have been then in progress. The accumulating, folding, solidification and crystallization of rocks attending all the rock-making and mountain-making through the Paleozoic, Mesozoic and Cenozoic eras, had greatly stiffened the crust in these parts, and hence, in after time, the continental movements resulting from the lateral pressure necessarily appeared over the more northern portion of the continent, where the accumulations and other changes had been relatively small. To the subsidence which followed the elevation the ice-cap may have contributed in some small degree. But the great balancing movements of the crust of the continental and oceanic areas then going forward must have had a greatly preponderating cause in the oscillating agency of all time, lateral pressure within the crust.